Top Quark Mass
Theory Developments

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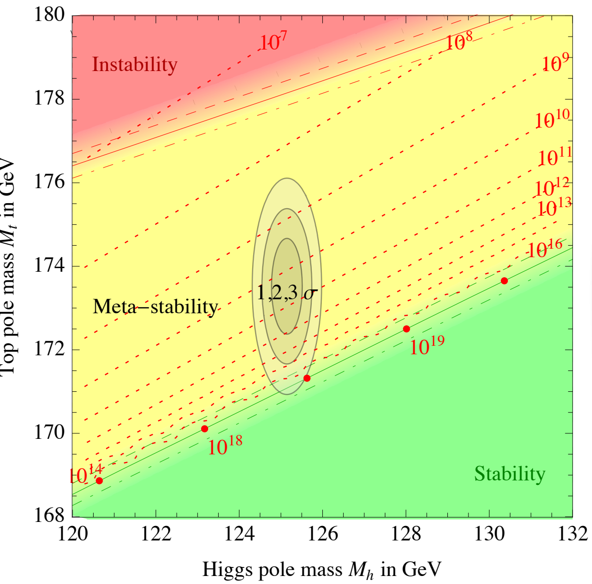
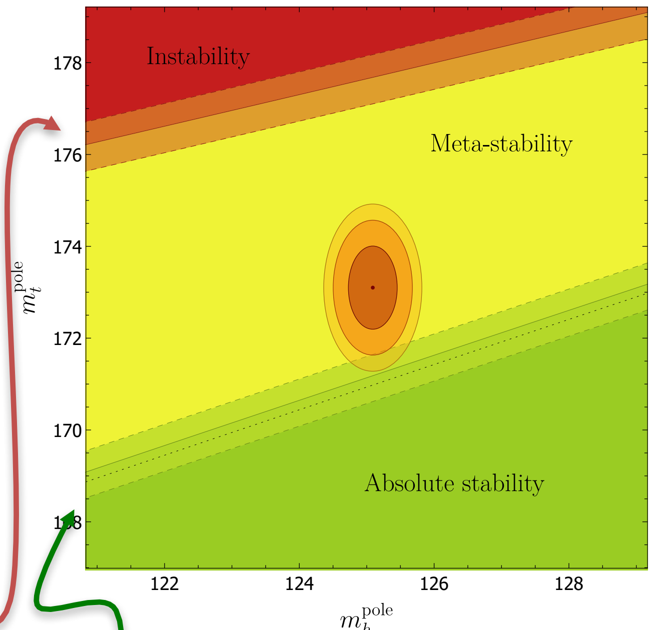
Motivation update

Old phase diagram (arXiv:1307.3536)



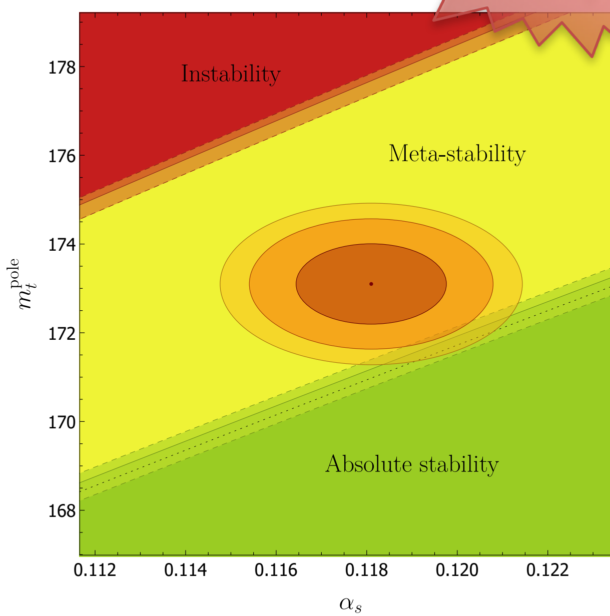
New phase diagrams (1708.08124)

Higgs-Top mass plane



α_s - top mass plane

New!



What changed?

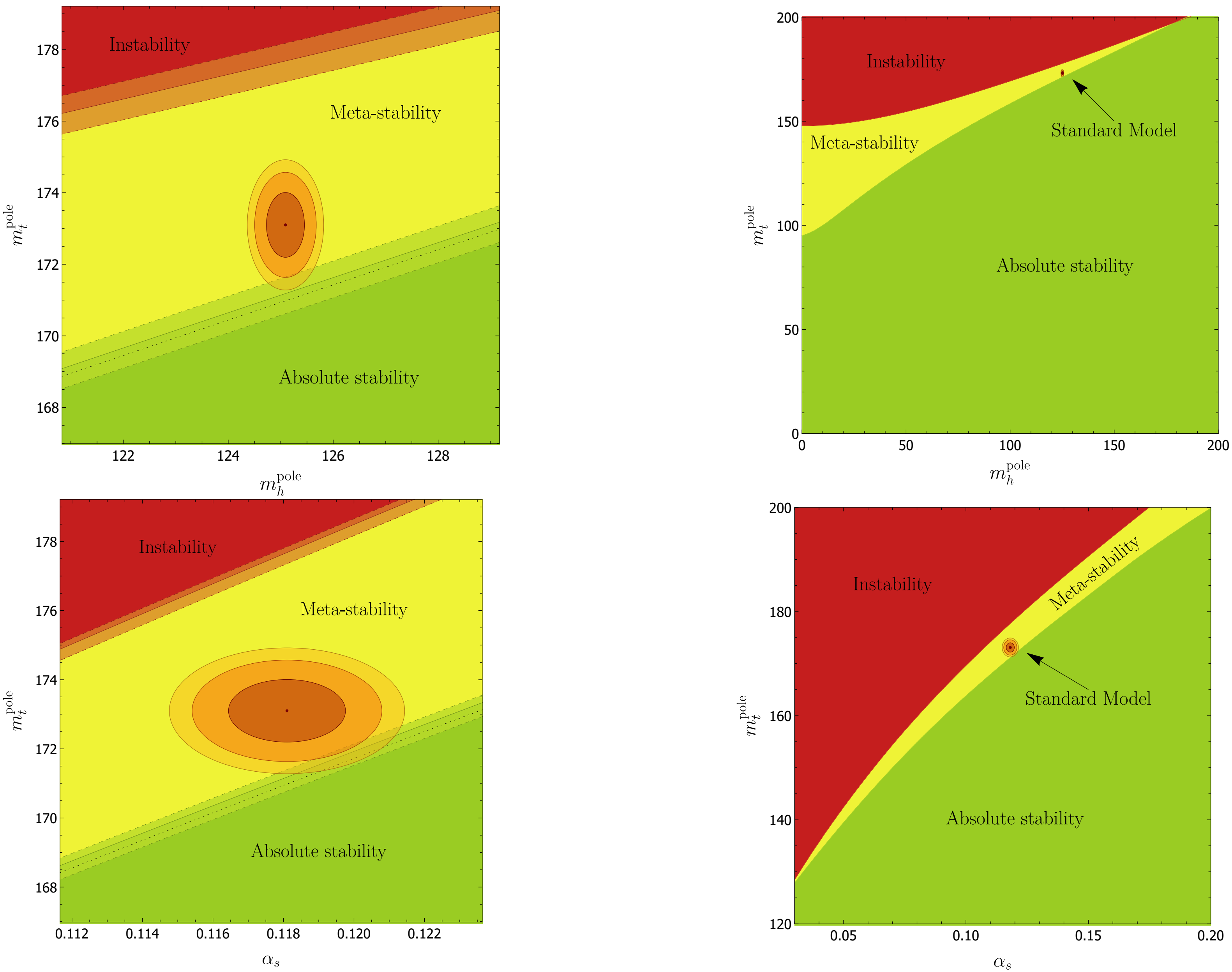
- Complete instability boundary to NLO
- Stability boundary gauge invariant
- EW/QCD threshold effects included
- Proper handling of correlated errors
- Universe lifetime = 10^{139} years

- Higgs mass uncertainty smaller than α_s uncertainty

For 3σ exclusion need

- $\Delta m_t < 250$ MeV or
- $\Delta\alpha_s < 0.00025$

Fine tuning?



Instability
Meta-stability
Absolute stability
178
176
174
172
170
168
122
124
126
128
m_t^{pole}
m_h^{pole}
Instability
Meta-stability
Standard Model
Absolute stability
200
150
100
50
0
0
50
100
150
200
m_t^{pole}
m_h^{pole}
Instability
Meta-stability
Absolute stability
178
176
174
172
170
168
0.112
0.114
0.116
0.118
0.120
0.122
m_t^{pole}
α_s
Instability
Meta-stability
Standard Model
Absolute stability
200
180
160
140
120
0.05
0.10
0.15
0.20
m_t^{pole}
α_s

Top mass schemes

Best measurements come from reconstructing hadronic top decays

CMS (7&8 TeV): 172.44 ± 0.48 GeV
ATLAS (8 TeV): 172.84 ± 0.70 GeV
PDG 2014: 173.1 ± 0.6 GeV

Is there an additional scheme ambiguity?

Monte Carlo mass
- Parameter in PYTHIA/Herwig
- Depends on tuning
- How to relate to theoretically precise mass (i.e. MSbar)?

Pole mass
- Well defined theory mass
- Translation to MSbar has a ~110 MeV ambiguity 1605.03609
  - Related to non-convergence of asymptotic series
- Equals MC mass at leading order

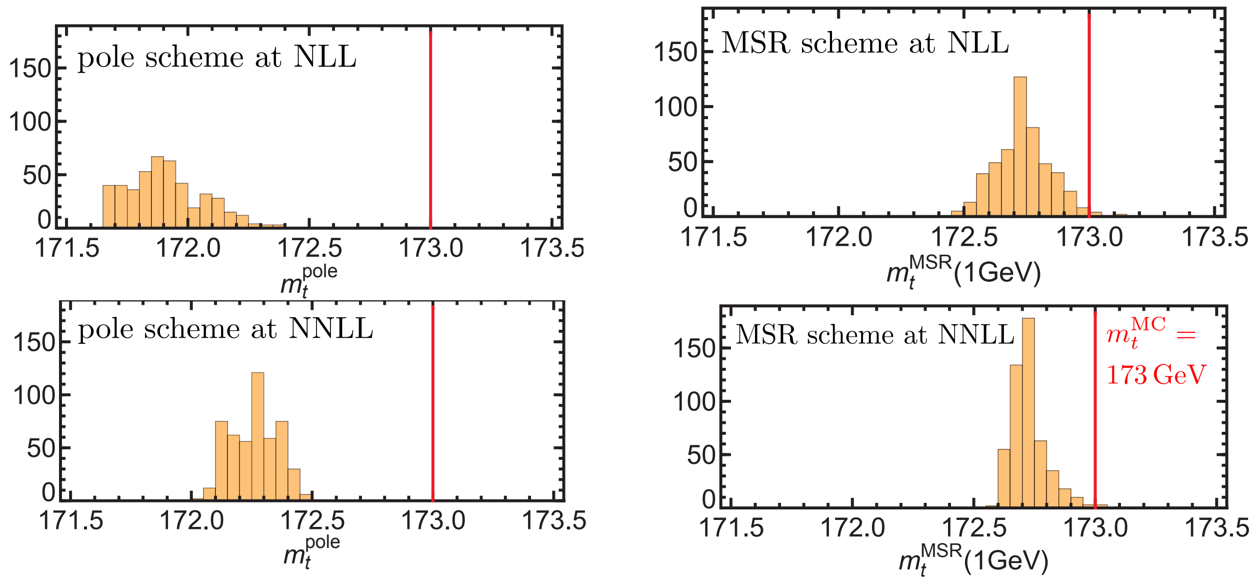
MSR mass
- Introduced by Hoang et al. 0803.4214
- Converts to MSbar mass without ambiguity
- Used in precision boosted top calculations e.g. 1708.02586
- Closer to MC mass?
  - Conversion depends on tuning

Higher-order QCD effects

Convergence better using MSR than pole for boosted tops (1608.01318)

MC mass to pole mass conversion

MC mass to MSR mass conversion



Which MC mass is it?

$$m_t^{\mathrm{MC}} \longrightarrow m_t^{\mathrm{MSR}} \longrightarrow m_t^{\overline{\mathrm{MS}}}$$

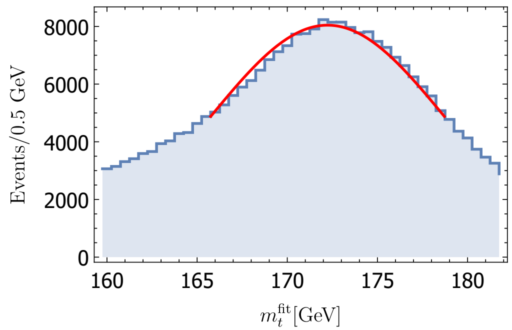
Unboosted tops, should use pp -> tt at **NLO** matched to parton showers

- Including interference and decay in PowhegBox (1607.04538)
- Uses NLO pole mass $m_t^{\mathrm{pole}} \longrightarrow m_t^{\overline{\mathrm{MS}}}$
- Still tuning ambiguity induced by matching to PS

Reducing MC mass uncertainty

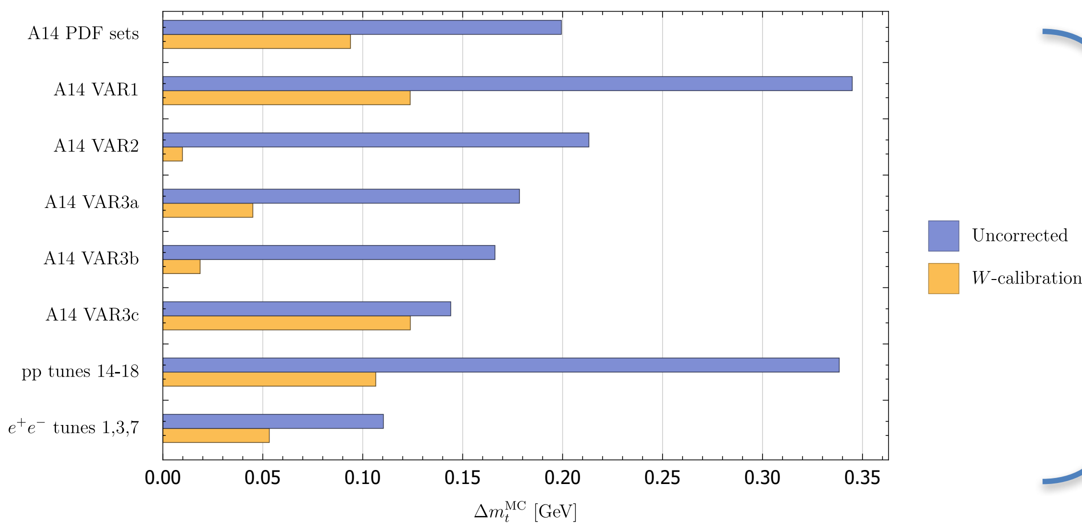
MC mass is not a single mass

- Depends on process (e^+e^- vs pp)
- Depends on tuning
- Should be $m_t^{\rm MC}(\alpha_s, \text{ISR}, \text{FSR}, \text{had-model}, \cdots)$



Estimate tuning uncertainty by varying tunes

- Use ATLAS A14 tunes, cross check with others
- Simulate top events, cluster, and fit shape to extract mass



$$\Delta m_t^{\rm MC} = 530 MeV$$

W calibration: $m_t^{\rm fit} \to m_t^{\rm fit} \frac{m_W^{\rm MC}}{m_W^{\rm fit}}$

- Corrects for Jet Energy Scale (exp. Issue)
- Also corrects for soft radiation
  - ISR, FSR, Underlying Event, Pileup…

$$\Delta m_t^{\rm MC} = 200 MeV$$

Reducing MC mass uncertainty

Additional reduction with jet grooming

Jet Trimming (arXiv:0912.1342)

- Reclusters with kT
- Drops soft subjets or size R_{sub}

$$p_T^{\text{subjet}} < f_{\text{cut}}\ p_T^{\text{jet}}$$

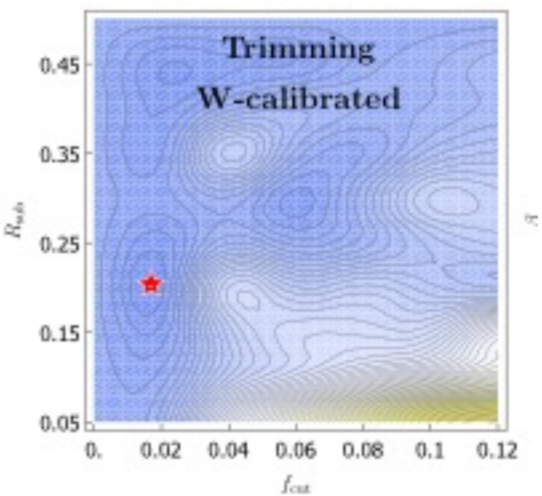
Soft Drop (arXiv:1402.2657)

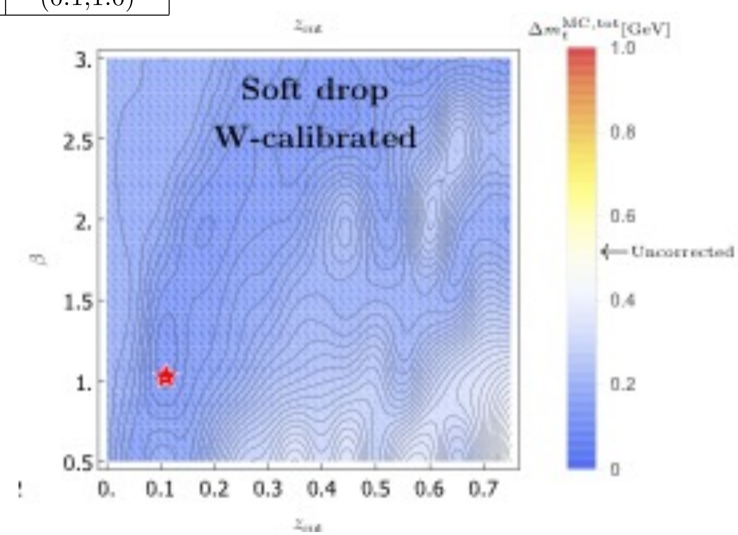
- Reclusters with Cambridge/Aachen
- Drops soft branches of tree

$$\frac{\min(p_{T1}, p_{T2})}{p_{T1}+p_{T2}} = z > z_{\text{cut}} \left(\frac{\Delta R_{12}}{R}\right)^{\beta}$$

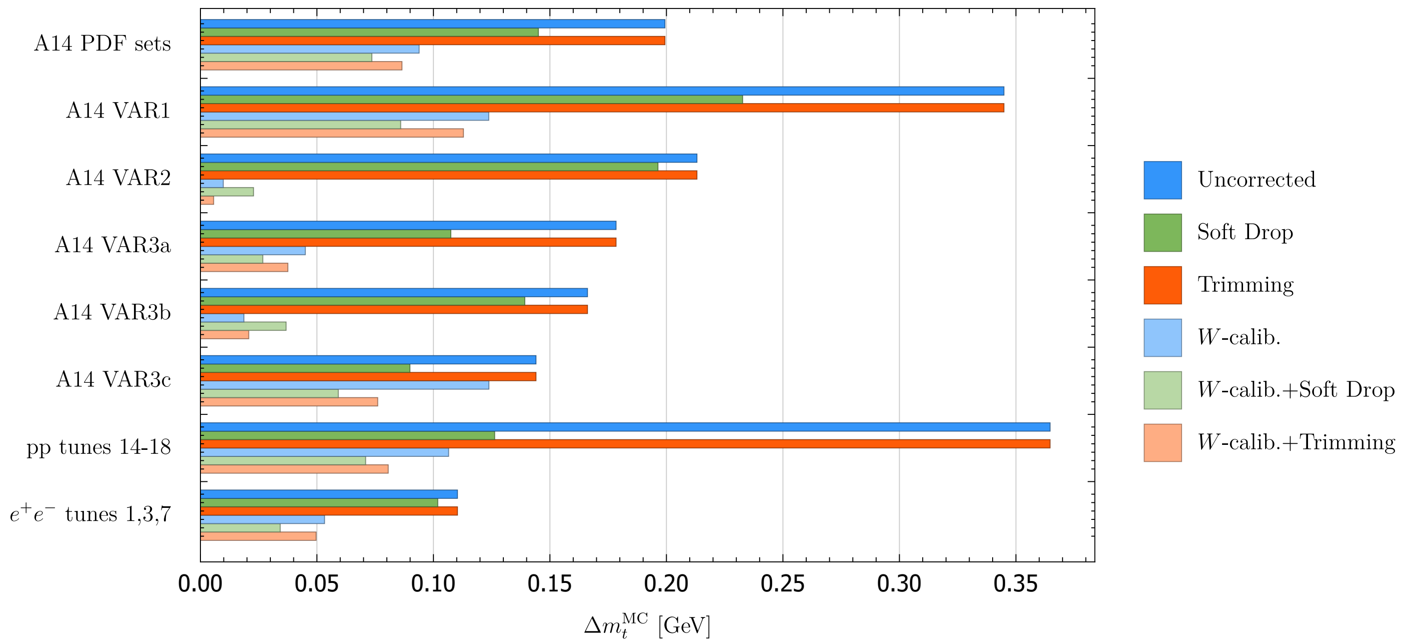
Table 1: Optimal grooming parameters:

	Trimming $(f^*_{\text{cut}}, R^*_{\text{sub}})$	Soft Drop $(z^*_{\text{cut}}, \beta^*)$
without W-calibration	–	(0.05,0.5)
with W-calibration	(0.02,0.2)	(0.1,1.0)





Reducing MC mass uncertainty



	without W calibration		with W-calibration	
No grooming	530 MeV		200 MeV	(−62%)
Trimming	530 MeV	(0.0%)	170 MeV	(−68%)
Soft drop	390 MeV	(−26%)	140 MeV	(−74%)
e^+e^-	110 MeV	(−79%)	50 MeV	(−90%)

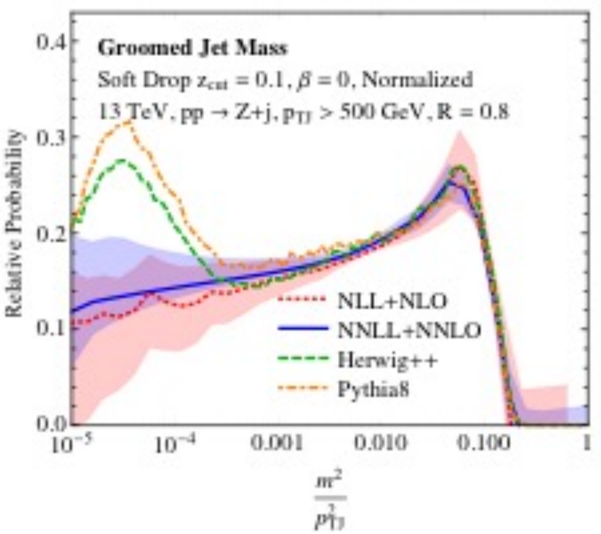
Soft-drop reduces uncertainty to

$$\Delta m_t^{\mathrm{MC}} = 140 MeV$$

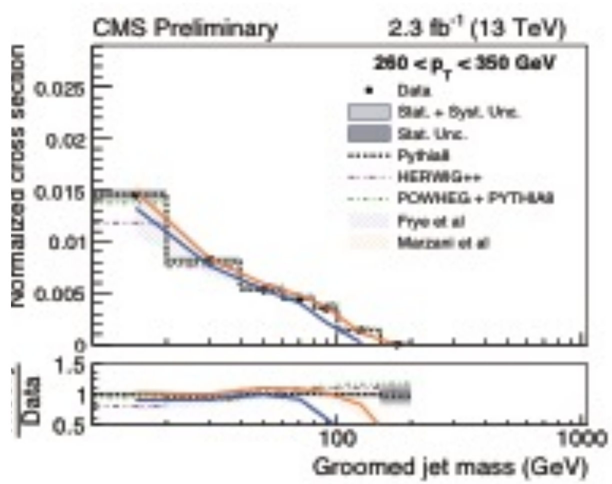
Soft drop is theory-friendly

- Soft drop jets are process-independent (no event-wide color connections)
- Resummation known to NNLL level
- Active area of theory research
- CMS just measured soft-drop jet mass (SMP-16-010)

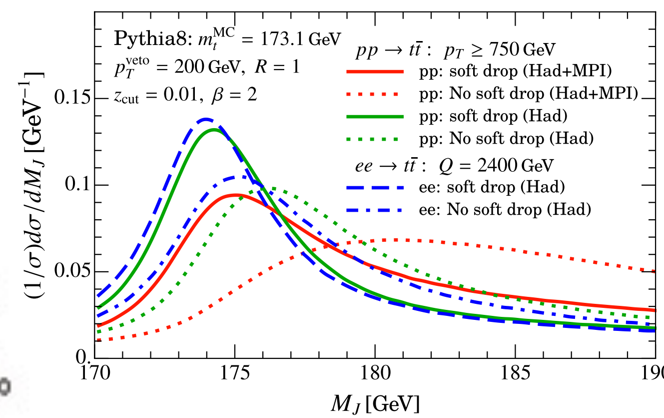
Jet mass theory
(arXiv 1603.06375)



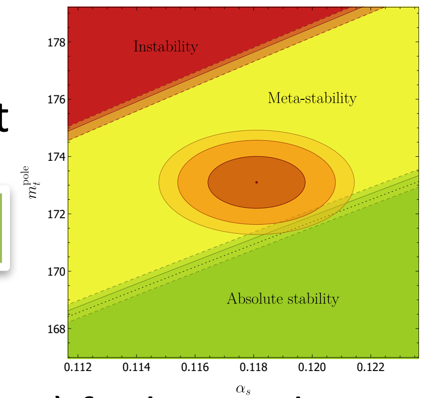
Jet mass experiment
CMS (SMP-16-010)



Boosted top jet theory
(arXiv 1708.02586)



Summary



- Mass reconstruction in semileptonic top decays is currently the best method for top mass measurement

Need Δm_t < 250 MeV to exclude absolute stability

- May be possible convert to MC mass to well-defined mass (MSR mass) for boosted tops
- Unboosted tops should use **NLO** top mass distribution, matched to MC
  - Available in Powheg (see 1607.04538)
  - NLO reduces pure theory uncertainty
  - Residual tuning uncertainty same as MC mass tuning uncertainty

$$m_t^{\rm pole} \longrightarrow m_t^{\overline{\rm MS}}$$

Converting between schemes is a theory problem
Reducing sensitivity to tuning has to be done during measurement

- Top MC mass is tuning dependent $\Delta m_t^{\rm MC} = 530 MeV$
- Dependence reduced with
  - W-Calibration (JES calibration) $\Delta m_t^{\rm MC} = 200 MeV$
  - Soft-drop jet grooming $\Delta m_t^{\rm MC} = 140 MeV$
    - Theory friendly